THE INFLUENCE OF THE INDIAN OCEAN TSUNAMI ON CORAL REEFS OF WESTERN THAILAND, ANDAMAN SEA, INDIAN OCEAN.

BY

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ABSTRACT

Coral reefs of the west coast of Thailand were minimally affected by the Indian Ocean tsunami of December 26, 2004. Results of rapid assessment surveys prior to the present study revealed that only 13% of 174 sites visited along the west coast of Thailand were severely damaged with 60% of sites showing little or no damage.
These preliminary results were confirmed in the present study by an evaluation of 17 long-term monitoring sites where reef assessment had been regularly made over the last 15-25 years. Only four of these sites showed marked damage with reductions of coral cover in the order of 5-16%, though it was estimated that coral cover had been reduced by approximately 40% on the southwest tip of Pai Island in Krabi Province where long-term monitoring had not been carried out prior to the tsunami. At impacted sites, damage consisted of overturned massive corals, broken branching corals and smothering of corals by sediments and coral rubble with these effects being greatest in shallow waters. No clear patterns were observed in terms of coral diversity at damaged locations pre- and post- tsunami.

Overall damage was extremely localized affecting only small sectors of reef which were exposed to the full force of the tsunami waves. It is estimated that damaged sites will recover naturally in a time span of 5-10 years provided there is no major setback such as bleaching-induced coral mortality.

INTRODUCTION

The effects of hurricanes and cyclones are well documented in the literature (Hughes, 1993) but there is little or no reference to the effects of tsunamis on coral reef ecosystems despite the fact that tsunamis have been generated in the coral seas around Sumatra and the Andaman and Nicobar Islands in the past (Bilham, 2005). At approximately 09.55h on 26 December, 2004, during a high water spring tide, a series of tsunami waves struck the west coast of Thailand following a major earthquake registering 9.3 on the Richter scale off northwest Sumatra (Stein and Okal, 2005). Four days later, the Thai Ministry of Natural Resources and Environment and staff from nine national universities launched a rapid survey of marine habitats along the entire 700km coastline

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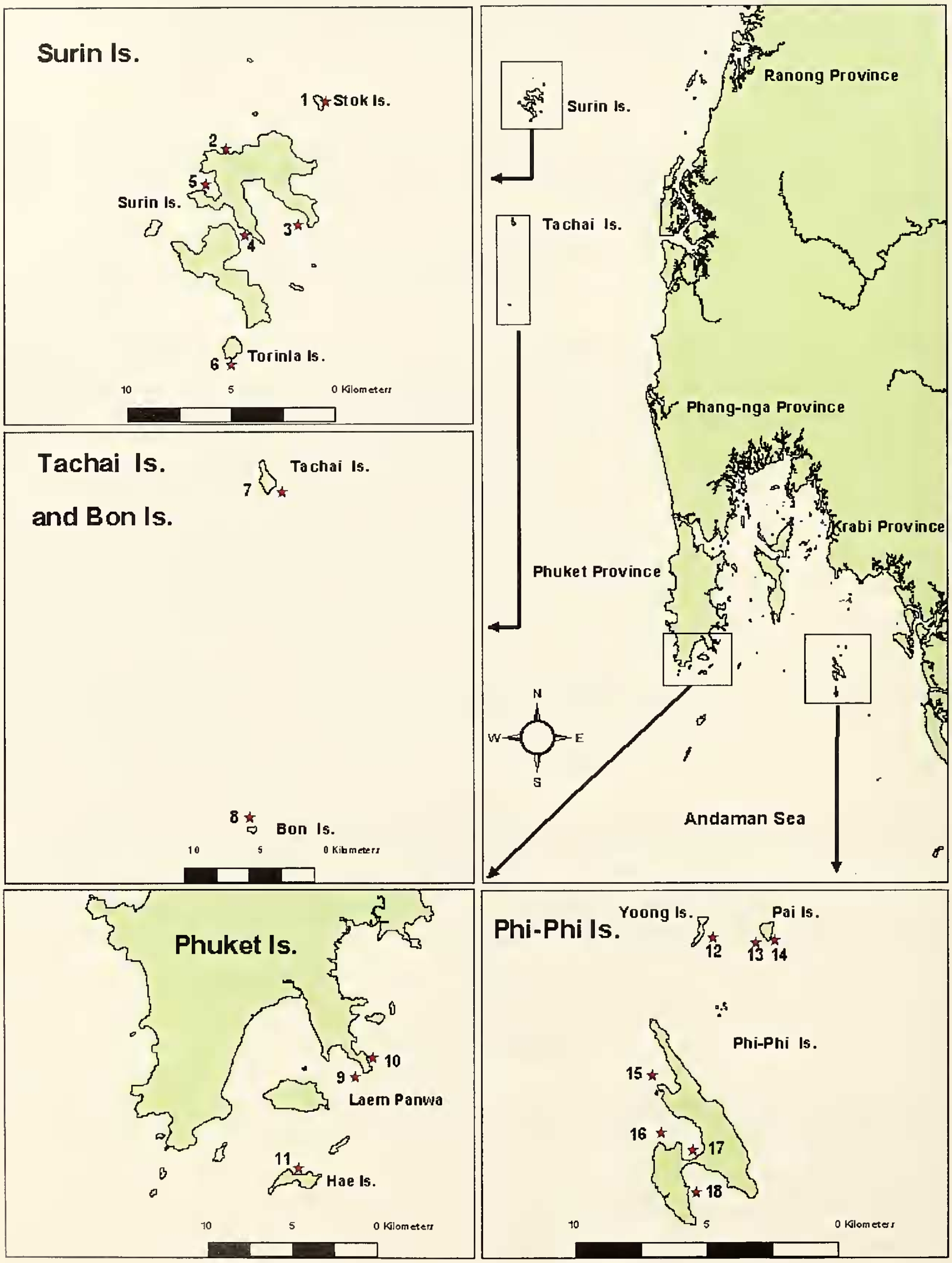

Figure 1. Maps showing the location of monitoring sites 1-18 along the west coast of Thailand.

of west Thailand. They visited coral reefs at 174 sites and noted that up to 105 sites were unaffected or showed very little damage while 30 showed low level damage (11-30% coral cover affected), 16 displayed moderate damage (31-50% coral cover affected) and 23 were severely damaged (>50% coral cover affected) (Department of Marine and Coastal Resources, 2005, Satapoomin et al., 2006).

This initial survey concluded that the northernmost coastline (Ranong, and Phang-nga Provinces) and its offshore islands (Surin and Similans) were more severely impacted than the south (e.g., Phuket, Krabi except Phi Phi Island, Trang and Satun) with shallow reefs on wave-exposed islands and shorelines being more vulnerable to wave-induced damage. The destructive impact of the tsunami appeared to be dependent on the degree of exposure to the waves, the surrounding sea bottom topography and depth of water over the reef.

Unlike many other countries in the region, Thailand boasts a valuable long-term data base on coral cover and diversity of fringing reefs that characterize the coastline bordering the Andaman Sea. This data base includes information from shallow reef slopes (Phongsuwan and Chansang, 1992) and intertidal reef flats (Brown et al., 1990, 2002, Brown and Phongsuwan, 2004) that have been monitored regularly over the last 10-25 years. Using this data and information from the rapid assessment survey of 2005, this paper evaluates the impact of the 2004 tsunami and predicts the likely outcome for reefs that were severely damaged.

METHODS

Figure 1 and Table 1 describe the locations of 18 monitoring sites visited in the study. Seventeen of these sites are long-term monitoring locations with over 10 years worth of regular coral-reef surveillance data while one was a site that had been severely affected by the tsunami but which had not previously been subject to regular monitoring. All sites, apart from site 10 on the Laem Pan Wa Peninsula of southeast Phuket, were reef slopes. Site 10 was an intertidal reef flat that extended approximately 150m from the shoreline and was dominated by massive poritid and faviid corals with branching species (*Acropora hyacinthus, Acropora aspera, Acropora pulchra, Acropora humilis* and *Pocillopora damicornis*) at the reef edge. Of reef-slope sites all locations, apart from sites 8 and 15, were upper reef slopes at depths ranging from approximately 3-7m. Depths at sites 8 and 15 were approximately 10m. Reef slopes were generally mixed communities often dominated by either massive (*Porites lutea*) or branching (*Porites rus, Porites nigrescens*) poritid corals, together with a variety of branching *Acropora* spp.

Permanently marked 100 m long transects, running parallel to the coastline and along a particular depth contour, were monitored using standard methods (Phongsuwan and Chansang, 1992) at all sites apart from site 10. At the latter location a series of 12 permanently marked 10m long reef transects were established across the reef flat in 1979 at 10 m intervals (Brown et al., 1990). For the purposes of this study, only the four outer reef flat transects were considered. Measures of coral cover and diversity (H_1^c) were calculated according to the methods of Loya (1972) at all locations.

Tidal data were collected from the Ko Taphao Noi tide gauge located on the eastern side of the Laem Panwa Peninsula, Phuket. Hourly sea levels were computed from the records for this station which are held at the University of Hawaii/National Oceanographic Data Center Joint Archive for Sea Level.

Table 1. Showing names, positions and site numbers of coral-reef monitoring stations.

Site number	Site name	Latitude	Longitude
SURIN ISLANDS			
1	Stok	9°28.486'N	97°54.375'E
2	North Surin	9°27.290'N	97°51.872'E
3	North Mayai	9°25.473'N	97°53.864'E
4	Park Front	9°24.923'N	97°52.656'E
5	Mai-ngam Bay	9°26.309'N	97°51.199'E
6	South East Torinla	9°22.038'N	97°52.099'E
OFF-SHORE ISLANDS			
7	Tachai	9°17.508'N	98°19.879'E
8	Bon	9°43.486'N	98°06.587'E
PHUKET AREA			
9	Laem Panwa West	7°47.956'N	98°24.526'E
10	Laem Panwa East	7°48.539'N	98°24.692'E
11	Hae Island	7°44.725'N	98°22.740'E
PHI-PHI ISLANDS			
12	Yoong	7°48.826'N	98°46.615'E
13	South West Pai	7°48.956'N	98°47.647'E
14	East Pai	7°48.970'N	98°48.050'E
15	Phi-Phi-Lana	7°45.845'N	98°45.960'E
16	Lodalum	7°44.764'N	98°46.360'E
17	Yongkasem	7°44.517'N	98°45.915'E
18	Phi –Phi-Tonsai	7°43.352'N	98°46.364'E

RESULTS

Relatively few of the long-term monitoring sites showed any effects of the tsunami with the majority of sites along the Thai coastline appearing in exceptionally good condition after the event (Fig. 2). The main damage on reefs affected by the tsunami included overturned massive corals (Fig. 3a), broken branching corals (Fig. 3b), and covering of live coral surfaces by sediments (Fig. 3c).

Figure 2. A mixed coral community on the upper reef slope at Site 5 in the Surin Islands after the tsunami.

The damage caused was extremely localised with overturned corals at one point and untouched corals only metres away. On sheltered intertidal reef flats where there had been extensive stands of dead branching *Acropora aspera* on the reef edge, as a result of lowered sea level in 1997-98, broken branches of dead *Acropora* were carried inshore by the tsunami waves to cover highly localised areas of living massive species. In some cases partial mortality of living coral surfaces resulted from smothering and abrasion by these dead coral branches. Of the seventeen 10 m transects surveyed on the intertidal reef flat only one was affected in this way, highlighting the very limited and localised nature of damage caused by the tsunami waves.

Figure 3. Types of tsunami-related damage to coral reefs (**a**) Overturned massive *Porites* colony (**b**) verturned and broken *Acropora florida* colony (**c**) Sediment-covered *Porites* colony.

Percentage of coral cover monitored over time at selected sites is shown in Table 2 and Figure 4. Sites shown in Table 2 represent locations where cover data have been collected irregularly over the last 16 years. Figure 4 illustrates changes in coral cover at five sites where monitoring has been carried out on a more frequent basis over a 16-26 year period. Lower coral cover between pre- and post-tsunami surveys was noted at sites 6,7,15 and 16 (Table 2). These were also sites where tsunami-related coral damage had been observed. No quantitative data are available pre-tsunami for site 13 though coral cover estimates from manta surveys suggest an approximate coral cover of 40-50% in mid 2004 (Phongsuwan and Arunwattana, 2005). Significant damage, in terms of overturned massive corals and broken *Acropora* branches, was noted at this wave-exposed location and these effects are reflected in the low cover observed after the tsunami. At sites 15 and 16, reduced coral cover was attributed to damage caused by increased sediment loads, generated by the tsunami waves, which smothered coral tissues.

Table 2. Percentage coral cover over time at selected monitoring stations. (n/a = data no available)

a) Surin Islands

Site No.	1989	1990	1993	1998	2001	2005
1	n/a	37.7	n/a	11.7	16.9	27.1
2	50.0	60.0	29.0	19.1	22.6	25.0
4	42.0	49.7	36.0	15.3	20.2	48.2
6	n/a	48.7	n/a	32.4	n/a	23.6

b) Offshore Islands

Site No.	1988	1989	1995	2001	2005
7	n/a	5.4	n/a	40.3	32.4
8	46.0	n/a	51.3	30.1	28.0

c) Phi-Phi Islands

Site No.	1988	1991	1995	1997	2000	2003	2005
12	n/a	n/a	n/a	n/a	28.5	n/a	37.2
13	n/a	n/a	n/a	n/a	n/a	n/a	13.1
14	n/a	n/a	n/a	n/a	28.2	n/a	44.2
15	28.3	n/a	34.2	n/a	29.1	n/a	14.5
16	n/a	n/a	n/a	n/a	n/a	28.0	23.8
17	n/a	n/a	30.1	35.8	29.4	30.6	34.2
18	63.5	68.6	50.5	59.4	47.2	52.8	51.6

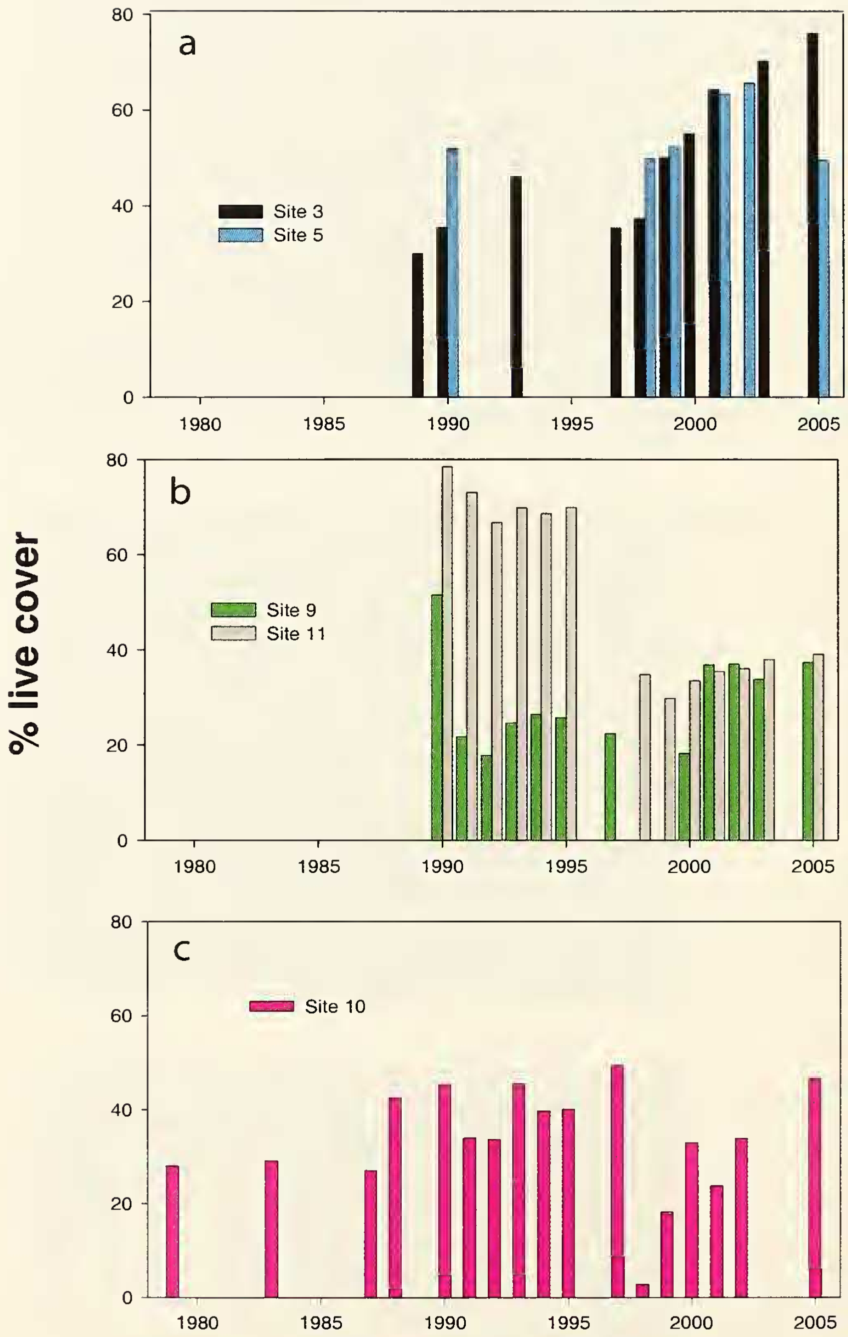

Figure 4. Changes in percentage coral cover over time at a) Sites 3 and 5 b) Sites 9 and 11 c) Site 10.

In Figure 4a, a decrease in coral cover in 2005 is evident only at Site 5 but this cannot be attributed to the tsunami and is most likely related to a mild bleaching event in 2003. At site 3, coral cover is as high in 2005 as has ever been recorded at this location since 1989. Figure 4b shows no loss of cover as a result of the tsunami at sites 9 and 11 although there was a marked drop in coral cover at site 9 between 1990 and 1991 as a result of an extensive bleaching event in 1991. There has been very little recovery at this location in subsequent years. At intertidal site 10, coral cover was lowest in 1997-98 during a period of exceptionally low sea level. Field observations at this location revealed no physical damage as a result of the tsunami and this was reflected in the high coral-cover values of 2005.

Generally diversity indices showed very little change over time at both affected and unaffected sites (data not shown) with no clear patterns emerging at sites affected by the tsunami.

DISCUSSION

The Indian Ocean tsunami of 2004 clearly had a limited effect upon the coral reefs of the Andaman Sea coast of Thailand. Remarkably, there appears to be few references to the effects of tsunamis on coral reefs in the literature despite a history of repeated tsunamis in the Indo-Pacific region. For example, a total of 35 tsunamis have been estimated to have impacted the Indonesian archipelago since the Krakatau tsunami of 1833 (Carey et al., 2001) while significant tsunami waves were reported following earthquakes at Car Nicobar in 1881 and in the Andamans in 1941 (Bilham et al., 2005). Coral reefs were mentioned in a report of a tsunami initiated as a result of an earthquake in the Philippine Fault Zone in S.E Mindanao in 1992 but only in terms of their ameliorating effects in reducing the wave height finally reaching the shore (Besana et al., 2004).

Although the heights of the tsunami waves are not reflected in the tidal measurements obtained for the relevant period at Ko Taphao Noi, Harada (2005) estimates tsunami wave heights to have been approximately 10m on the mainland inshore from sites 7 and 8, 3 m at sites 9, 10 and 11 and 5 m at sites 15 and 16. These heights were measured on site within four days of the arrival of the tsunami waves. Coral reef damage appears to have been mainly restricted to sites on the west-to- southwest sides of islands which are frequently exposed to southwest monsoon influences. Coastal topography and aspect of site similarly played an important role in influencing tsunami-related damage to coral reefs in northern Sumatra in December 2004 (Baird et al., 2005). While poorly attached massive corals at depth were displaced in Sumatra (Baird et al., 2005) damage was mainly restricted to shallow reef sites in Thailand.

At the few locations where negative impacts were observed along the Thai coastline, the type of damage noted was similar to that of hurricanes and cyclones with broken branching corals (Woodley et al., 1981, Woodley, 1993; Rogers, 1993) and dislodgement of often weakly attached massive colonies (Massel and Done, 1993) in shallow waters. Similar dislodgement of large colonies of *Acropora palifera* has been noted in Flores in eastern Indonesia following a tsunami (Tomascik et al., 1997). The extremely localized nature of the damage observed in the present study was also similar to that noted during hurricanes with only sectors of a reef affected (Woodley et al., 1981; Rogers, 1993) where susceptibility varied markedly between different coral species (Bythell et al., 1993). At impacted sites in Thailand, branching *Acropora* species were particularly susceptible (both plate-like varieties and arborescent forms) as were weakly attached massive *Porites* colonies.

There appears to be very little mention of deleterious effects of sediment mobilisation on coral reefs as a result of hurricane damage in the scientific literature. Rather, hurricane-mediated flushing of sediments has been described as benefiting coral reef development (Hubbard, 1986, 1992; Hillis and Bythell, 1998). Although sedimentation has caused some coral mortality at two sites around Phi Phi Island, sediment effects as a result of the tsunami have been limited. There are at least two reasons why this should be the case. Firstly, many of the corals which are dominant on Thai reefs are capable of efficient removal of sediment from their surfaces (Stafford-Smith, 1993) and secondly, flushing as a result of the tsunami waves and the spring tides occurring at the time would aid cleansing of coral surfaces. Indeed, improved water quality was noted at many sites following the tsunami along the Thai coastline probably as a result of strong flushing (Department of Marine and Coastal Resources, 2005). In Banda Aceh localized sediment damage to corals was reported after the tsunami, together with changes in sediment regimes that caused increased turbidity around coral reefs (Baird et al., 2005).

Where limited tsunami-induced reef damage has occurred on the Andaman Sea coast of Thailand, it is likely that natural recovery will take place within the next 3-5 years at low impact sites and within 5-10 years at locations with severe damage. The reasons for such a confident prognosis arise from three factors: first the exceptionally high growth rates of dominant corals in the region (Scoffin et al., 1992; Lough and Barnes, 2000); previous evidence of rapid reef recovery following damage from storm surges (Phongsuwan, 1991), sedimentation and lowered sea levels (Clarke et al., 1993; Brown et al., 2002; Brown and Phongsuwan, 2004); and the present generally good condition of reefs in the area. Such a rapid recovery does, however, depend on reefs not suffering from widespread mortality from other sources such as elevated sea temperatures. Although Hoegh-Guldberg (2004) has predicted, from theoretical models, annual bleaching and high coral mortality on the Thai coastline from the late 1970's onwards, the only marked bleaching mortality that has actually taken place to date occurred in 1991 and 1995 with very limited bleaching since these events (Phongsuwan, unpubl).

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